

Fundamental Study of Damping-Ratio Control in the Linear Vehicle Dynamics

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Recent trends toward vehicle electrification result in increased vehicle size and mass, as well as the widespread adoption of low rolling resistance tires. These changes adversely affect vehicle handling performance. Yaw inertia reduction control can improve responsiveness by controlling the vehicle dynamics to emulate a smaller yaw moment inertia than the actual vehicle. However, this control also increases yaw-rate overshoot.

To address this issue, ‘damping-ratio control’ method was proposed. This control generated an additional yaw moment proportional to the vehicle sideslip angle rate, and could suppress the overshoot while retaining the response improvement by the yaw inertia reduction control. The fundamental characteristics of this control method and its combined effect with the yaw inertia reduction control were investigated.

The damping-ratio control law was expressed as Eq. (1). This law applied a yaw moment proportional to vehicle sideslip angle rate.

$$M_{ZC} = G_D \dot{\beta} \quad (1)$$

where G_D was the gain of the angle rate.

Analysis using a linear bicycle model indicated that this control could adjust the damping ratio through G_D without affecting the steady-state characteristics or natural frequency. The damping ratio was given by Eq. (2).

$$\zeta = \frac{m(l_f^2 K_f + l_r^2 K_r) + I_Z(K_f + K_r)}{2l \sqrt{m I_Z K_f K_r (1 + AV^2)}} + \frac{G_D}{2} \frac{mV + \frac{2}{V}(l_f K_f - l_r K_r)}{2l \sqrt{m I_Z K_f K_r (1 + AV^2)}} \quad (2)$$

The frequency response analysis confirmed that increase of the damping ratio reduced the peak of the yaw rate as shown in Fig. 1 and this control could maintain the natural frequency and steady-state gain.

The ramp steering simulations showed that a higher damping ratio reduced the yaw rate overshoot with no effect on the peak timing and the steady-state characteristics, as shown in Fig. 2.

The damping-ratio control law combined with yaw inertia reduction control was expressed as Eq. (3).

$$M_{ZC} = (I_Z - I_Z^*) \dot{r} + G_D \dot{\beta} \quad (3)$$

where I_Z^* denoted the virtual yaw moment of inertia.

Simulation results shown in Fig. 3 showed that the yaw inertia reduction control alone improved the response performance but degraded overshoot. In contrast, the combined control reduced overshoot and preserved the response improvement. A parametric study varying the yaw inertia reduction ratio and damping ratio further revealed that an appropriate damping ratio could achieve both improved transient response and reduced overshoot relative to the uncontrolled vehicle, as shown in Fig. 4.

These results suggested that the proposed damping-ratio control could independently enhance damping characteristics and the combination of the two control laws achieved simultaneous improvement of vehicle response and suppression of yaw-rate overshoot.

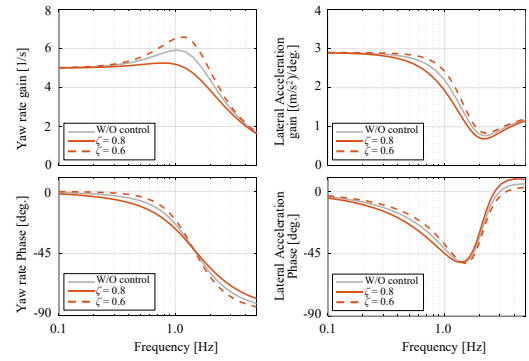


Fig. 1 Frequency response in ζ -control

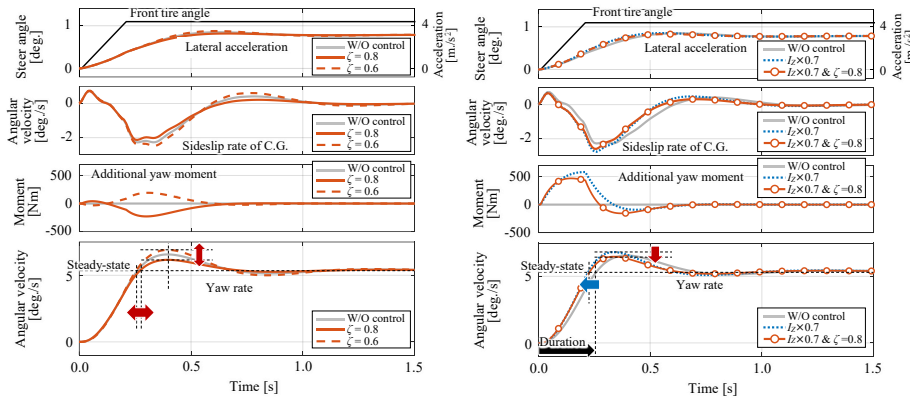


Fig. 2 Ramp response
in ζ -control

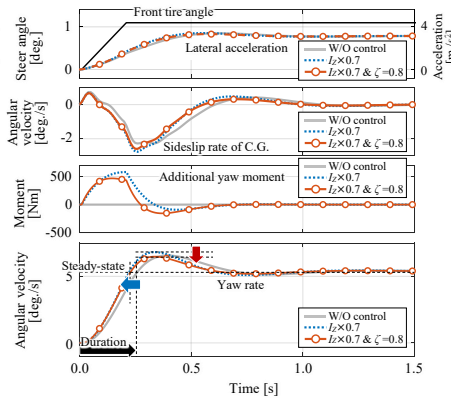


Fig. 3 Ramp response
in I_Z - ζ -control

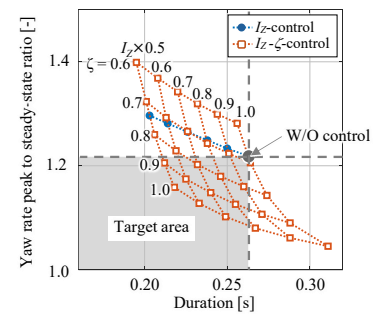


Fig. 4 Distribution of
responsiveness
and overshoot